## LCA Strategies: Best Available Techniques

# Proposal for an Integrated Approach for the Assessment of Cross-Media Aspects Relevant for the Determination of "Best Available Techniques" BAT in the European Union

**Jutta Geldermann, Christina Jahn, Thomas Spengler, Otto Rentz**

Deutsch-Französisches Institut für Umweltforschung (DFIU), University of Karlsruhe (TH), Hertzstr. 16, D-76187 Karlsruhe, Germany

**Corresponding author:** Dipl.-Wirtsch.-Ing. Jutta Geldermann; jutta.geldermann@wiwi.uni-karlsruhe.de

## Abstract

The EC Directive concerning integrated pollution prevention and control (IPPC Directive 96/61/EC) obliges all Member States to make an integrated assessment of the impacts on the environment "as a whole", as regards granting permission for and the operation of environmentally relevant industrial installations. The determination of "Best Available Techniques" BAT plays an essential role in the material transformation of the IPPC-Directive. An integrated approach for the assessment of cross-media aspects of techniques for the determination of BAT is outlined in this paper, which is grounded on the basic concept of Life Cycle Assessment (LCA), emphasising the need for decision support. The proposed assessment approach is applied to a case study sinter production in an integrated iron and steel works, which forms the base for several recommendations concerning further research.

Keywords: Best Available Technique (BAT), LCA; decision support; Integrated Pollution Prevention and Control (IPPC-Directive); IPPC-Directive

## 1 Introduction

On 24th September 1996 the EC passed the Council Directive 96/61/EC concerning Integrated Pollution Prevention and Control (IPPC-Directive), which obliges the Member States to take an "integrated approach to the protection of the environment" in the granting of permits for environmentally relevant industrial installations. This Directive lays down the frame of a formal procedure for the licensing of installations and furthermore pursues a protection of the environment that is not limited to single media. The aim is "... to achieve a high level of protection of the environment taken as a whole" (Article 1).

The "best available techniques" (BAT) play an essential part in the actual realisation; they will serve as a basis for the determination of reference values for emission limits and for the granting of permits for installations. In this context, cross-media aspects are to be taken into account in particular. The IPPC Directive gives partly very concrete requirements of the determination of BAT (*inter alia* in its Annex IV), but does not propose a particular method.

According to the IPPC Directive, a suitable assessment method should allow locally independent BAT to be determined for each industrial sector at EU-level. Industrial sectors corresponding to the definitions in Annex I of the IPPC Directive are listed as energy industries, production and processing of metals, mineral industry, chemical industry, waste management, and other activities.

The assessment must take into account *inter alia* the internationally relevant environmental quality standards and should, if that is required, be supplemented by locally especially relevant parameters for certain installations, without deviating from the approach of a locally independent BAT determination. In order to allow a practicable local application of BAT, the method should be built using modules for later additions. Neither the locally independent, nor the local method may, however, lead to a situation where a certain technique is being prescribed.

The determination of BAT at an international level, taking into account an agreed method for the assessment of cross-media aspects, is an essential step towards the harmonisation of the requirements for industrial installations. For this purpose, the EU sets up "Technical Working Groups" (TWG)[1], which determine BAT for the individual sectors

[1] The Technical Working Groups (TWG) are established under the umbrella of the IPPC Information Exchange Forum (IEF) to carry out the detailed technical work on the exchange of information for a given industrial sector (cf. Annex I of the IPPC-Directive). They comprise experts from EU-Member States, representatives from the particular industry and environmental NGOs (Non-governmental organisations); (cf. http://eippcb.jrc.es/).
The IEF is the forum for discussion of general and policy related issues relating to the information exchange and for final discussion of each BREF (BAT Reference Document). The IEF is chaired by DG XI and comprises representatives from each EU Member State, representatives of industry and environmental NGOs.



Int. J. LCA 4 (2) 94-106 (1999)

mentioned in the IPPC Directive from documents delivered by the national agencies for the environment and by industrial and environmental associations. For the purpose of the locally independent determination of BAT at EU-level, an integrated approach for the assessment of cross-media aspects is proposed in this paper, in order to offer a tool to the TWG for the determination of the BAT. This approach for the assessment of cross-media aspects of techniques for the determination is grounded on the basic concept of Life Cycle Assessment (LCA), emphasising the need for pragmatic decision support, as described firstly in this paper. Hereafter, the proposed assessment approach is applied to a case study sinter production in an integrated iron and steel works, as an example from one of the industrial sectors mentioned in the IPPC-Directive. On the one hand, the procedure of the proposed cross-media assessment approach is elucidated with the help of this case study, and on the other, the strength and weaknesses of the use of LCA for cross-media assessment for the identification of BAT as a consequence of the IPPC-Directive are discussed. From the insights gained in the case study, several recommendations for further research are derived in the conclusions.

## 2 The Proposed Cross-Media Assessment Approach for the Determination of BAT at EU-level

In order to meet the requirements of the IPPC Directive, an integrated approach for the assessment of techniques is proposed, which takes into account cross-media aspects relevant for the determination of BAT in the EU. As far as possible, existing approaches are incorporated in order to ensure the acceptance of the integrated approach. It is characterised by flow charts which structure the course of the decision process. Much scope and competence is left with the experts in the Technical Working Groups (TWG). Thus, an understandable and also pragmatic procedure is ensured, without impairing the consistency of the assessment.

**The basic procedure of the proposed integrated approach** for the determination of BAT at EU-level corresponds with the structure set by the ISO 14040 and with the Life Cycle Assessment (LCA), as developed and applied for the ecological assessment of packaging systems of drinks (UBA-Texte 52/95). For the application of the LCA according to UBA to BAT determination, several amendments are necessary, since LCA was originally designed for the comprehensive ecological assessment of the entire life cycle of a product. The advantage of LCA is the assessment of the potential harm of emissions to the environment by means of the "impact categories" (HEIJUNGS et al., 1992). Although these impact categories are still not complete and disputable in several aspects, this approach has the best scientific research background for pointing out the relation between emissions and their potential ecological impacts.

Therefore, the proposed integrated approach for BAT determination at EU-level is also structured in four steps: first screening, mass and energy balance, impact assessment and decision support. It should be noted that the used terms are suited to the requirements of BAT identification and the evaluation of techniques. The experts' discussion, which may take place at EU-level, e.g. within the framework of the work of the TWGs, is an integral part of the method. The objective of the method is to direct the discussion towards the main issues of technique selection. As soon as the BAT determination has become evident, the procedure can be cut short. **Figure 1** shows the basic scheme of the integrated method of assessment for the locally independent, sectoral BAT determination, taking into account cross-media aspects.

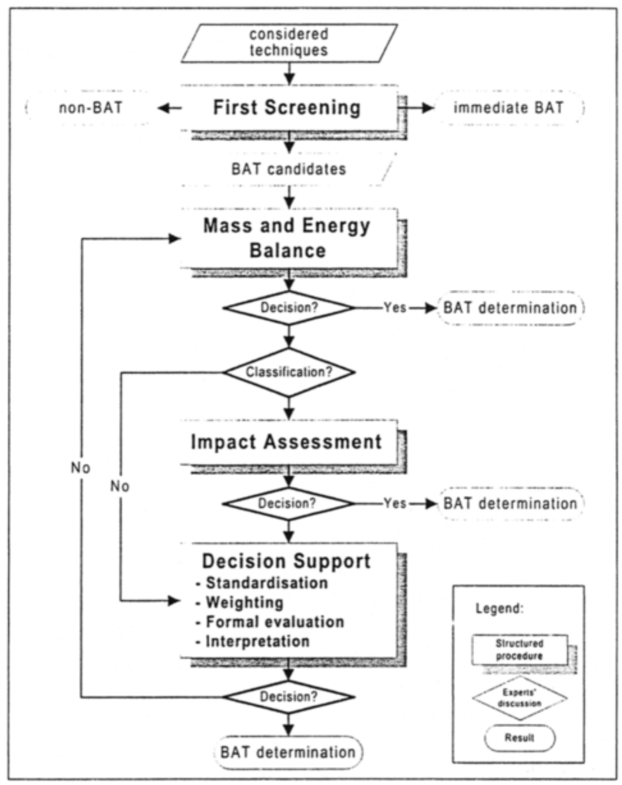


**Fig. 1:** Flow chart of the proposed cross-media aspects assessment approach for BAT determination

The **First Screening** includes the selection of the techniques which are to be examined from all available techniques described in national BAT notes or other relevant papers. The non-compliance with EU-wide binding emission limit values is to be used as a cut-off criterion for any examined technique and causes the classification of the particular technique as "non-BAT", if an improvement of that technique is not possible. If no EU-wide binding emission limit values are available, the TWGs could also agree on the application of other international and national emission limit values. At the same time, techniques without any relevant environmental impacts, if there are any, do not require a further detailed examination, if they are determined as "immediate BAT".

The other techniques, the so-called "BAT candidates" are submitted to the subsequent step of assessment.

In the **Mass and Energy Balance** all relevant input flows, emission and energy data of BAT candidates are compiled, using an uniform data format (SINGHOFEN, 1996). Experts then decide on an extension of the system through preliminary stages or additional operations, but also on the limitation of the examination on the relevant emissions and input flows. In the First Screening, but also in the drawing-up of the mass and energy balance, the experts' discussion thus limits and reduces the examination effort. If it is already possible to determine the BAT in the experts' discussion with the data gained in these two steps, the procedure can be cut short or proceeds directly with the decision support.

Otherwise the individual substances are classified in the **Impact Assessment** with regard to their potential environmental impacts and are – as far as possible – summarised in impact categories. It must be noted that the methodological and scientific framework for impact assessment is still being developed.

The modelling of the potential environmental impacts by means of impact categories is being criticised, since important toxicological issues are too complex to be reflected by rather simple impact assessment factors. The calculation of impact potentials largely removes spatial and temporal considerations, resulting in analytical and interpretative limitations. Some impact categories are defined using highly complex or unknown interdependencies such that the degree of uncertainty varies significantly between the impact categories (OWEN, 1996).

Despite of these criticisms, the use of LCA is considered as a valuable tool in environmental policy and in ecological assessments, as an additional basis for decisions (TROGE, 1997; MERKEL, 1997). Furthermore, the impact assessment factors developed by the CML Leiden (HEIJUNGS et al., 1992) are currently being extended and updated. If this step proves to be too comprehensive for the BAT determination, a by-pass is provided such that the Impact Assessment might be left out (→ *Fig. 1*).

The following impact categories for modelling the potential environmental impact of emissions are being put up for discussion within the context of the determination of BAT. According to the LCA as applied to the study on drink packaging systems (UBA-Texts 52/95), the impact categories

- Global warming
- Ozone depletion (stratosphere)
- Acidification of water and land
- Nutrification of water
- Photochemical oxidant formation

seem to be meaningful, since these categories have relevance on EU-level. For supporting a pragmatic ecological assessment of techniques, the impact categories

- Consumption of resources
- Human Toxicity
- Ecotoxicity
- (Hazardous) Waste

are modified and put up for discussion. Human toxic and ecotoxic substances are taken into account pragmatically by means of the environmental quality standards in the valid EU Directives as well as the WHO Air Quality Guidelines. For the assessment of waste and energy generation a first simple classification is done, and only if significant differences arise, a comprehensive assessment will be carried out. The comprehensive assessment of the impact potential of aquatic emissions is not only done in the ecotoxicity category, but also in the newly introduced category "protection of the marine environment". In order to include the requirements mentioned in the IPPC Directive, further impact potentials may be formulated for the determination of BAT in particular industrial sectors.

This condensing of the inventory data collected in the mass and energy balance by means of the impact assessment serves as preparation for the subsequent valuation and eases the final decision. Due to a lack of scientific work on cross-media aspects there is, however, no scientific basis available for aggregating the data gained from ecological assessments, so that a clear ranking of examined techniques can be derived from it. If the group of BAT is clearly evident for the experts from the information gained in the impact assessment, the method ends at this point.

Otherwise, the **Decision Support** offers a convincing data preparation and a structured procedure to allow an efficient experts' discussion in order to determine the BAT. Firstly, the impact potentials of the considered techniques are standardised by a comparison of each impact potential with the average value of the considered techniques. The graphical representation of the standardisation is often sufficient for the BAT determination in the experts' discussion. Since not all impact categories have the same influence on the overall decision, the weighting of the considered criteria is necessary in the experts' discussion, in order to differentiate the significance of aspects which are relevant for the decision. If the experts wish so, the weighting might be supported

- by the estimation of the ecological relevance of the impact categories, which have to be valid in general in all sectors, and

- by the estimation of the quantitative relevance of the impact potentials of the considered techniques by a comparison with the corresponding impact potentials in the EU, if European emission data are available.

Weighting factors should be set by an upper level, e.g. the Information Exchange Forum (IEF). If no decision is possible, a formal method for decision support is provided. This formal method for multicriteria decision support is based

on pairwise comparisons of each pair of considered techniques with regard to each relevant criterion. Within this method, ecological, technical and even economic parameters, measured in different units of measurement, can be simultaneously evaluated. Its result is not a numerical order, but a graphical representation, which forms a suitable basis for the final BAT determination in the experts' discussion and a critical review (BRANS et al., 1986; RENTZ et al., 1998). The procedure of the proposed approach for cross-media assessment is being explained in more detail in the following with a case study from the metal industry.

## 3 Application of the Integrated Approach to the Assessment of Sinter Techniques

In order to demonstrate the application of the proposed approach for the assessment, the complete course of the method is shown in the case study "technical assessment for sinter plants". In the following, the application of the proposed integrated approach is described rather briefly. For the full documentation with comprehensive explanation, see (RENTZ et al., 1998).

The sinter techniques are chosen as a case study for the BAT identification, since the techniques and their emissions are relatively well documented, although different modes of data collection and varying measuring points limit the availability of comparable data. Therefore, the described techniques should be regarded as hypothetical, and the application of the method will not determine BAT, but will only show the feasibility of the proposed approach and validate it. The aim of the case study is to investigate the data availability and to analyse the shortcomings of the approach in order to stimulate further research.

The sintering plant is the main important aggregate in the integrated iron and steel works for the preparation of iron ores. In a blast furnace, only iron ores of a relatively large size can be used. Small iron ore particles as fines and concentrates reduce the permeability and hamper the process in the blast furnace. The sintering plant essentially consists of a large travelling grate of heat resistant cast iron. In the sintering process, the small particles are baked (sintered) into larger pieces (10 - 50 mm), which can be fed into the blast furnace. The necessary heat for sintering is produced by coke as a fuel. Raw materials require blending prior to the sintering operation. Additives are mixed to the ore blend, like lime and olivine. In the sintering process, flue dusts, mill scales etc. stemming from the production process of iron and steel making, can be recycled (CAPPEL, 1973; BOTHE, 1993; UBA-Berichte 96/05). **Figure 2** shows the sinter process schematically.

The proposed integrated approach for the assessment of cross-media aspects is applied to six techniques for sintering, which differ mainly in their means of gas cleaning. Three techniques use an electric precipitator, one technique uses a fabric filter in addition, another technique uses a cyclone for the dust absorption, while the last technique uses the airfine process.

In the **First Screening**, all six techniques are determined as candidate BAT, since none of them is regarded immediately as BAT, but all of them comply with the emission limit values relevant at EU-level. The scope of the assessment is reduced to four techniques: Technique A as the average of the three techniques using an electric precipitator, Technique B - D as described above.

For these four techniques, the **Mass and Energy Balance** is compiled for the reference quantity of 1 t sinter. It should be noted, that due to the impaired data availability caused by insufficiently specified inputs and differing monitoring and reporting regulations, the given figures are not completely comparable.

The sinter process is basically a source of particulate matter and gaseous emissions (DUTCH, 1997) (→ *Table 1*):

- particulate matter emissions from handling, crushing, screening and conveying of sinter feedstock;
- flue gas emissions from the sinter process ($SO_2$ from the combustion of sulphur compounds in the sinter feed; $NO_x$ from combustion of organic compounds in the sinter feed

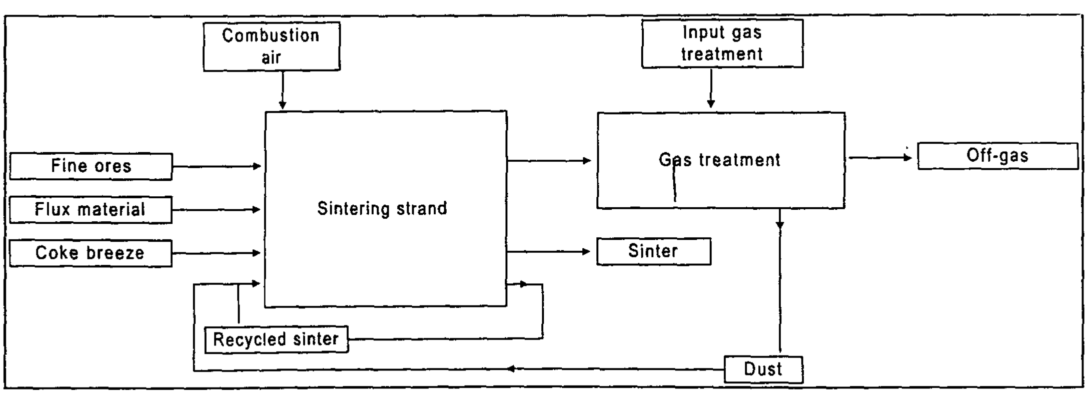


**Fig. 2:** Scheme of the Sinter process

or from the reaction of molecular $N_2$ or $O_2$; Hydrocarbons from pyrolysis and incomplete combustion of carbon containing raw materials; PCDD/PCDF because of special conditions in the sinter plant; heavy metals (As, Cd, Cr, Hg, Ni, Pb, and Zn) from the inputs);

- waste water and solid waste from flue gas treatment;
- cooling and rinsing water;
- energy demand.

From the most important emissions of sinter plants into air, $SO_2$, CO and to a less extent, $NO_x$ are rather equally emitted by all four techniques. The techniques differ with regard to particulate matter, dioxines, heavy metals, and aquatic emissions.

The classification of the consumptions and emissions takes place in the **Impact Assessment**. The impact potentials of the techniques are calculated by multiplying the emissions with the corresponding impact factors. **Table 2** demonstrates the conversion of the emissions of technique D into the corresponding impact potentials. Several substances are classified in multiple impact categories, such as $SO_2$ and $NO_x$. It

Table 1: Selected positions of the mass and energy balance for the considered sinter techniques

| Input and output | Substance/Energy | Technique A | Technique B | Technique C | Technique D | Unit per t sinter |
|---|---|---|---|---|---|---|
| Energy | Fossil resources | 1700 | 1560 | 1650 | 1600 | MJ PE |
| | Electric energy | 395 | 425 | 345 | 410 | MJ PE |
| Atmospheric emissions | Dust | $7.65\cdot10^{-2}$ | $9.21\cdot10^{-3}$ | $6.48\cdot10^{[illegible]}$ | $1.10\cdot10^{-1}$ | kg |
| | CO | 17.25 | 31.30 | 23.76 | 39.60 | kg |
| | $SO_2$ | $8.32\cdot10^{-1}$ | 1.311 | 1.350 | $8.20\cdot10^{-1}$ | kg |
| | $NO_x$ | $4.10\cdot10^{-1}$ | $5.27\cdot10^{-1}$ | $4.86\cdot10^{-1}$ | $4.00\cdot10^{-1}$ | kg |
| | NMVOC | $8.61\cdot10^{-2}$ | $4.60\cdot10^{-2}$ | $3.05\cdot10^{-1}$ | $2.50\cdot10^{-2}$ | kg |
| | Chloride ions as HCl | $3.62\cdot10^{-2}$ | $2.86\cdot10^{-2}$ | $4.54\cdot10^{-2}$ | $5.90\cdot10^{-2}$ | kg |
| | Fluoride ions as HF | $3.52\cdot10^{-3}$ | $4.60\cdot10^{-4}$ | $1.14\cdot10^{-2}$ | $1.29\cdot10^{-3}$ | kg |
| | PCDD/PCDF | $3.45\cdot10^{-9}$ | $1.84\cdot10^{-9}$ | $6.48\cdot10^{-9}$ | $4.46\cdot10^{-10}$ | kg |
| | As | $1.00\cdot10^{-5}$ | $3.68\cdot10^{-7}$ | $4.32\cdot10^{-5}$ | $1.10\cdot10^{-6}$ | kg |
| | Cd | $1.40\cdot10^{-4}$ | $5.71\cdot10^{-7}$ | $1.30\cdot10^{-4}$ | $6.69\cdot10^{-6}$ | kg |
| | Cr | $1.21\cdot10^{-4}$ | $4.42\cdot10^{-6}$ | $4.32\cdot10^{-5}$ | $4.46\cdot10^{-6}$ | kg |
| | Cu | $3.54\cdot10^{-4}$ | $1.84\cdot10^{-6}$ | $1.30\cdot10^{-4}$ | $3.79\cdot10^{-5}$ | kg |
| | Hg | $4.51\cdot10^{-5}$ | $1.49\cdot10^{-5}$ | $4.32\cdot10^{-5}$ | $2.23\cdot10^{-5}$ | kg |
| | Mn | $7.18\cdot10^{-4}$ | $2.03\cdot10^{-6}$ | $5.44\cdot10^{-4}$ | $2.01\cdot10^{-5}$ | kg |
| | Ni | $9.76\cdot10^{-5}$ | $4.60\cdot10^{-6}$ | $7.46\cdot10^{-5}$ | $1.10\cdot10^{-6}$ | kg |
| | Pb | $8.75\cdot10^{-4}$ | $8.47\cdot10^{-6}$ | $9.91\cdot10^{-3}$ | $9.58\cdot10^{-5}$ | kg |
| | Sn | $9.18\cdot10^{-5}$ | $7.00\cdot10^{-7}$ | $9.44\cdot10^{-5}$ | $1.30\cdot10^{-4}$ | kg |
| | Tl | $1.95\cdot10^{-5}$ | $2.21\cdot10^{-7}$ | $1.56\cdot10^{-5}$ | $4.46\cdot10^{-6}$ | kg |
| | Zn | $2.40\cdot10^{-3}$ | $4.60\cdot10^{-5}$ | $3.67\cdot10^{-4}$ | $2.23\cdot10^{-6}$ | kg |
| Aquatic emissions | Chloride | 0 | 0 | 0 | $3.06\cdot10^{-4}$ | kg |
| | $SO_4$ | 0 | 0 | 0 | $1.55\cdot10^{-4}$ | kg |
| | Solid particlee | 0 | 0 | 0 | $5.11\cdot10^{-7}$ | kg |
| | Fe | 0 | 0 | 0 | $1.45\cdot10^{-8}$ | kg |
| | Cr | 0 | 0 | 0 | $5.69\cdot10^{-10}$ | kg |
| | Cu | 0 | 0 | 0 | $3.97\cdot10^{-9}$ | kg |
| | Zn | 0 | 0 | 0 | $1.64\cdot10^{-9}$ | kg |
| | Ni | 0 | 0 | 0 | $3.08\cdot10^{-9}$ | kg |
| | Cd | 0 | 0 | 0 | $1.28\cdot10^{-10}$ | kg |
| | Al | 0 | 0 | 0 | $1.80\cdot10^{-8}$ | kg |
| | As | 0 | 0 | 0 | $5.61\cdot10^{-11}$ | kg |
| | Pb | 0 | 0 | 0 | $4.00\cdot10^{-10}$ | kg |
| | Hg | 0 | 0 | 0 | $8.81\cdot10^{-11}$ | kg |
| | CN-volatile | 0 | 0 | 0 | $1.28\cdot10^{-9}$ | kg |
| | Fluoride (F) | 0 | 0 | 0 | $4.26\cdot10^{-7}$ | kg |
| | Sulfide (S) | 0 | 0 | 0 | $3.84\cdot10^{-9}$ | kg |
| | $NH_4$-N | 0 | 0 | 0 | $7.13\cdot10^{-6}$ | kg |
| | $NO_3$-N | 0 | 0 | 0 | $1.10\cdot10^{-6}$ | kg |
| | $NO_2$-N | 0 | 0 | 0 | $4.12\cdot10^{-8}$ | kg |
| | TOC | 0 | 0 | 0 | $1.07\cdot10^{-6}$ | kg |
| | COD | 0 | 0 | 0 | $8.12\cdot10^{-6}$ | kg |
| Hazardous Waste | Filter cake, dry | 0 | 0 | 0 | 0.15 | kg |

should be noted that the energy demand is not converted into its contribution to the impact categories, since the impact potentials are increased by less than 5% by the converted energy. Energy demand, however, will be taken into account as total energy consumption, calculated as primary energy content and measured in MJ. Although primary energy content is not regarded as an impact category, it should be taken into consideration as an important criterion (→ *Table 3*).

The data are summarised for each considered technique to its total impact potential, as shown in the graphical representation in **Figure 3**. A closer look at this graphical representation reveals that the emissions into air are well registered within the impact categories, while the conversion of aquatic emissions is debatable: On the one hand, the impact categories concerning the medium water as proposed by [UBA-Texte 52/95], nutrification and acidification, are mainly determined by the secondary impact of the emissions

**Table 2:** Impact assessment for sinter technique D

| | Substance | Mass per ton product | Impact category | Impact assessment factor | Impact potential per ton product |
|---|---|---|---|---|---|
| **Air** | Dust | $1.10 \cdot 10^{-1}$ kg | HT | $2.50 \cdot 10^{7}$ m³ Air/kg | $2.75 \cdot 10^{6}$ m³ Air |
| | | | ETA | $2.50 \cdot 10^{7}$ m³ Air/kg | $2.75 \cdot 10^{6}$ m³ Air |
| | CO | 39.6 kg | HT | $1.00 \cdot 10^{5}$ m³ Air/kg | $3.96 \cdot 10^{6}$ m³ Air |
| | $SO_2$ | $8.20 \cdot 10^{-1}$ kg | AP | 1 kg $SO_2$-Equ. | $8.20 \cdot 10^{-1}$ kg $SO_2$-Equ. |
| | | | HT | $2.50 \cdot 10^{7}$ m³ Air/kg | $2.05 \cdot 10^{7}$ m³ Air |
| | | | ETA | $2.50 \cdot 10^{7}$ m³ Air/kg | $2.05 \cdot 10^{7}$ m³ Air |
| | $NO_x$ | $4.00 \cdot 10^{-1}$ kg | AP | 0.7 kg $SO_2$-Equ. | $2.80 \cdot 10^{-1}$ kg $SO_2$-Equ. |
| | | | NP | 0.13 kg $PO_4^{3-}$-Equ./kg | $5.20 \cdot 10^{-2}$ kg $PO_4^{3-}$-Equ. |
| | | | HT | $2.00 \cdot 10^{7}$ m³ Air/kg | $8.00 \cdot 10^{6}$ m³ Air |
| | | | ETA | $2.00 \cdot 10^{7}$ m³ Air/kg | $8.00 \cdot 10^{6}$ m³ Air |
| | NMVOC | $2.50 \cdot 10^{-2}$ kg | POCP | 0.416 kg Ethen-Equ./kg | $1.04 \cdot 10^{-2}$ kg Ethene-Equ. |
| | Chloride as HCl | $5.90 \cdot 10^{-2}$ kg | AP | 0.88 kg $SO_2$-Equ. | $5.19 \cdot 10^{-2}$ kg $SO_2$-Equ. |
| | Fluoride as HF | $1.29 \cdot 10^{-3}$ kg | AP | 1.6 kg $SO_2$-Equ. | $2.06 \cdot 10^{-3}$ kg $SO_2$-Equ. |
| | PCDD/PCDF | $4.46 \cdot 10^{-10}$ kg | ME | 0.7 | $3.12 \cdot 10^{-10}$ kg |
| | As | $1.10 \cdot 10^{-6}$ kg | ME | 0.5 | $5.50 \cdot 10^{-7}$ kg |
| | Cd | $6.69 \cdot 10^{-6}$ kg | HT | $1.00 \cdot 10^{12}$ m³ Air/kg | $6.69 \cdot 10^{6}$ m³ Air |
| | | | ME | 0.7 | $4.68 \cdot 10^{-6}$ kg |
| | Cr | $4.46 \cdot 10^{-6}$ kg | ME | 0.5 | $2.23 \cdot 10^{-6}$ kg |
| | Cu | $3.79 \cdot 10^{-5}$ kg | ME | 0.5 | $1.90 \cdot 10^{-5}$ kg |
| | Hg | $2.23 \cdot 10^{-5}$ kg | HT | $1.00 \cdot 10^{9}$ m³ Air/kg | $2.23 \cdot 10^{-4}$ m³ Air |
| | | | ME | 0.7 | $1.56 \cdot 10^{-5}$ kg |
| | Mn | $2.01 \cdot 10^{-5}$ kg | HT | $1.00 \cdot 10^{9}$ m³ Air/kg | $2.01 \cdot 10^{4}$ m³ Air |
| | Ni | $1.10 \cdot 10^{-6}$ kg | ME | 0.5 | $5.50 \cdot 10^{-7}$ kg |
| | Pb | $9.58 \cdot 10^{-5}$ kg | HT | $5.00 \cdot 10^{8}$ m³ Air/kg | $4.79 \cdot 10^{4}$ m³ Air |
| | | | ME | 0.7 | $6.71 \cdot 10^{-5}$ kg |
| | Zn | $2.23 \cdot 10^{-6}$ kg | ME | 0.5 | $1.12 \cdot 10^{-6}$ kg |
| **Water** | Cr, water | $5.69 \cdot 10^{-10}$ kg | ME | 0.5 | $2.85 \cdot 10^{-10}$ kg |
| | Cu, water | $3.97 \cdot 10^{-9}$ kg | ME | 0.5 | $1.99 \cdot 10^{-9}$ kg |
| | Zn, water | $1.64 \cdot 10^{-9}$ kg | ME | 0.5 | $8.20 \cdot 10^{-10}$ kg |
| | Ni, water | $3.08 \cdot 10^{-9}$ kg | ME | 0.5 | $1.54 \cdot 10^{-9}$ kg |
| | Cd, water | $1.28 \cdot 10^{-10}$ kg | ETW | $1.00 \cdot 10^{9}$ m³ Water/kg | $1.28 \cdot 10^{-1}$ l Water |
| | | | ME | 0.7 | $8.96 \cdot 10^{-11}$ kg |
| | As, water | $5.61 \cdot 10^{-11}$ kg | ME | 0.5 | $2.81 \cdot 10^{-11}$ kg |
| | Pb, water | $4.00 \cdot 10^{-10}$ kg | ME | 0.7 | $2.80 \cdot 10^{-10}$ kg |
| | Hg, water | $8.81 \cdot 10^{-11}$ kg | ETW | $1.00 \cdot 10^{9}$ m³ Water/kg | $8.81 \cdot 10^{-2}$ l Water |
| | | | ME | 0.7 | $6.17 \cdot 10^{-11}$ kg |
| | COD, water | $8.12 \cdot 10^{-6}$ kg | NP | 0.022 kg $PO_4^{3-}$-Equ./kg | $8.12 \cdot 10^{-6}$ kg $PO_4^{3-}$-Equ./kg |
| **Waste** | Filter cake, dry | $1.50 \cdot 10^{-1}$ kg | A | 1 kg | $1.50 \cdot 10^{-1}$ Kg |

**Legend:**

HT: Humantoxicity
ETA: Ecotoxicity, air
AP: Acidification
NP: Nutrification
POCP: Formation of photochemical oxidants
ME: Protection of the marine environment
ETW: Ecotoxicity, water
A: Hazardous waste

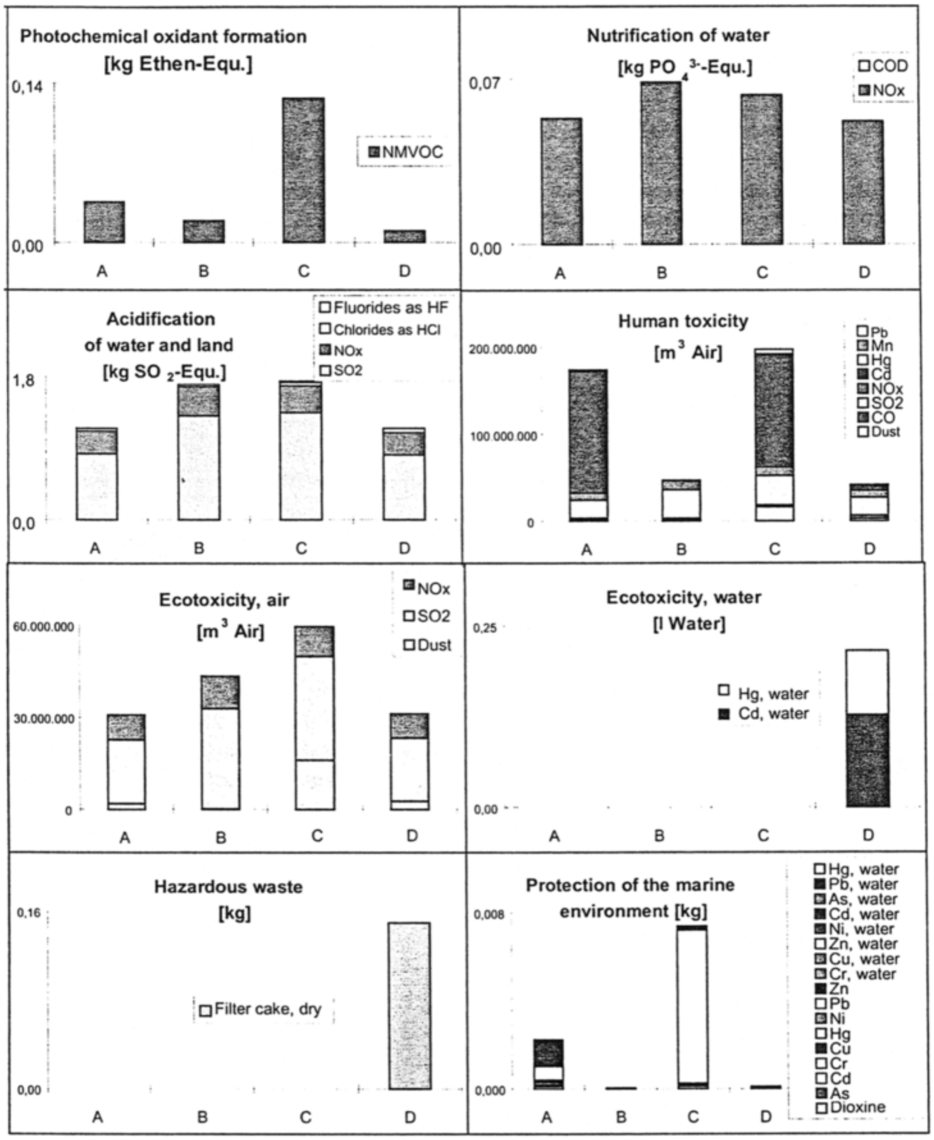


**Fig. 3:** Graphical representation of the impact categories of the four sinter techniques

into air by $NO_x$ and $SO_2$. $NO_x$ is converted into four impact categories (nutrification, acidification, humantoxicity and atmospheric ecotoxicity), but for the assessment of sinter plants, $NO_x$ is regarded to be of less relevance than other substances.

On the other hand, the modified impact category ecotoxicity concerning water and the newly introduced impact category protection of the marine environment, are mainly determined by the regarded quantities. It is striking, that technique D (airfine process), solely causing emissions directly into water, has the lowest impact potential in the impact category protection of the marine environment. This can be explained by the fact that the aquatic emissions rarely contribute to this impact category because of the minor amounts emitted, while the considered atmospheric emissions arise in amounts larger by the factor $10^5$. Furthermore, the share of Pb of that impact category seems to be exaggerated. Moreover, the impact of the PCDD/PCDF, one of the most important emissions from sinter plants, seems to be not sufficiently regarded in the impact categories. On these points, further research is needed in order to develop appropriate impact assessment factors. Emissions of definite relevance, which are not well represented within the impact categories, have, however, to be taken into account as criteria for the BAT determination. Therefore, they are considered in the decision table (→ *Table 3*) in addition to the discussed impact potentials. The primary energy demand, given as [MJ], is also taken into account as a criterion.

In the **Decision Support**, a comparison of the impact potentials of each considered technique with the average

Table 3: Decision Table for the case study *sinter production*

| **Criteria** | | **Technique A** | **Technique B** | **Technique C** | **Technique D** | **Unit of** |
|---|---|---|---|---|---|---|
| **Impact category** | | **Total impact potential** | | | | **Measurement** |
| Photochemical oxidant formation | | 35.8 | 19.1 | 127 | 10.4 | $10^{-3}$ kg Ethene-Equ. |
| Nutrification | | 53.2 | 68.4 | 63.2 | 52.0 | $10^{-3}$ kg $PO_4^{3-}$-Equ. |
| Acidification | | 1.16 | 1.71 | 1.75 | 1.15 | kg $SO_2$-Equ. |
| Humantoxicity | | 174 | 47.3 | 197 | 42.0 | $10^6$ m³ Air |
| Ecotoxicity, air | | 30.9 | 43.5 | 59.7 | 31.3 | $10^6$ m³ Air |
| Ecotoxicity, water | | 0 | 0 | 0 | 0.216 | l Water |
| Hazardous waste | | 0 | 0 | 0 | 0.15 | kg |
| Protection of the marine environment | | 2.24 | 0.0454 | 7.39 | 0.111 | $10^{-3}$ kg |
| **Data (derived) from mass and energy balance** | | | | | | |
| Consumption of | Fossil energy | 1.700 | 1.560 | 1.650 | 1.600 | MJ |
| energy | Electric energy | 395 | 425 | 345 | 410 | MJ |
| Air | Sn | 91.8 | 0.7 | 94.4 | 130 | $10^{-6}$ kg |
| | Tl | 19.5 | 0.221 | 15.6 | 4.46 | $10^{-6}$ kg |
| | PCDD/PCDF | 3.45 | 1.84 | 6.48 | 0.446 | $10^{-9}$ kg |
| Aquatic emissions | | no | no | no | yes | |

**Annotation:** All values are related to the reference quantity of 1 ton of sinter.

value of the considered techniques, the standardisation, is suggested. Due to the differences in the values in the individual impact categories (→ *Table 3*), the standardisation improves the clarity and eases the subsequent weighting of the impact categories. **Figure 4** – which might be regarded as a standardised summary of **Figure 3** – shows the standardised impact potential, calculated according to the formula (only considering values unequal to zero)

*standardised impact potential of a technique t =*

$$\frac{\textit{impact potential of technique } t}{\textit{mean value of all techniques } t = 1 \ldots T}\ .$$

The standardised relevant data on consumption and energy from the Mass and Energy Balance, which cannot be converted into impact potentials, are calculated in analogy. The higher the standardised impact potential, the larger is the potential impact on the environment. The mean value of the considered techniques corresponds to the value 1. Figure 4 illustrates that technique C (using a cyclone) has the highest impact potentials for photochemical oxidant formation, acidification, humantoxicity, ecotoxicity and protection of the marine environment in comparison with the other three techniques. Technique D yields the lowest impact potentials in most categories, but the aquatic emissions must be taken into account as well. Furthermore, for the interpretation of

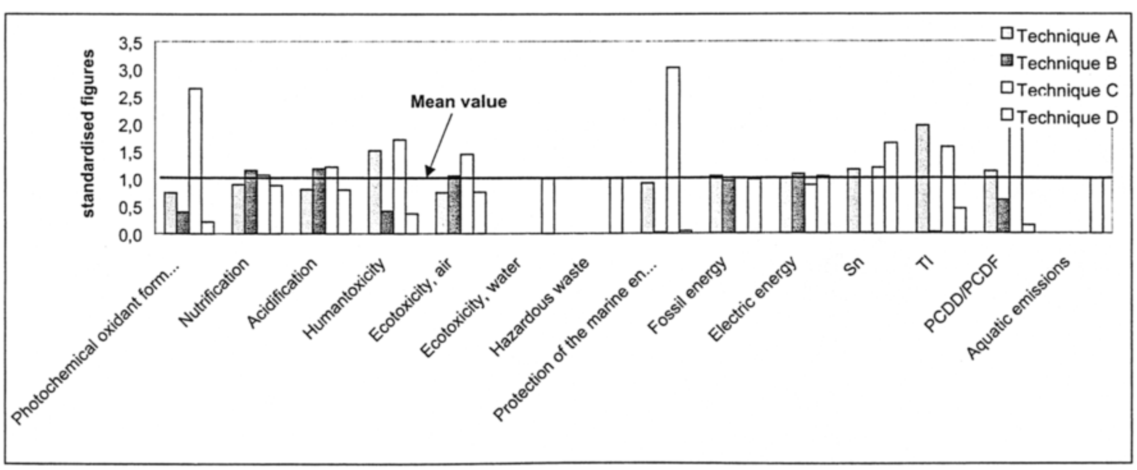


**Fig. 4:** Standardisation by comparing the impact potentials of the considered techniques with their average values

the graphical representation of the standardisation, it should be noted that not all impact categories are of same relevance for the BAT determination.

For the differentiation of the significance of the considered aspects for the decision, the weighting is oriented towards the ecological relevance of the impact categories and the estimation of the quantitative relevance of the impact potentials of the considered techniques by a comparison with the corresponding impact potentials in the EU, if European emission data are available, calculated on the basis of the "specific contribution":

*specific contribution of the considered techniques in the impact category*

$$= \frac{\textit{Mean value of impact potentials of the considered techniques}}{\textit{EU-wide impact potential}}$$

$$= \frac{\sum \textit{average emissions of the considerd techniques} \cdot \textit{impact assessment factor}}{\sum \textit{EU-wide emissions} \cdot \textit{impact assessment factor}}$$

Since not for all emissions, which contribute to an impact category, EU-wide data are available, the specific contribution is calculated approximately for the time being. **Table 4** shows a possible summary of the verbal classification according to the ecological relevance of the impact categories and the quantitative relevance of the calculated impact potentials for the four considered techniques for sinter production. Because only for the impact categories photochemical oxidant formation, nutrification, acidification, humantoxicity and ecotoxicity$_{air}$ can specific contributions be calculated based on EU-wide data, the quantitative relevance of the other impact categories and relevant criteria from the Mass and Energy Balance should be estimated in the experts' discussion. The ecological relevance of the impact categories Humantoxicity, Ecotoxicity and Protection of the marine environment as well as of the relevant criteria from the Mass and Energy Balance should also be approximately classified in the experts' discussion, e.g. by the *IEF*. It should be noted that there is no defined substitution rate between the verbal predicates, which rather serve as a rough orientation for differentiating the significance of the criteria.

In the sense of the pragmatic setting of weights for the impact categories and the relevant mass and energy flows, the experts should be asked to rank the significance of these criteria. The information concerning the ecological relevance of the impact categories and the quantitative relevance of the calculated impact potentials serve as a basis, since both together give indications for the total relevance and therefore an orientation for the weighting. A pragmatic possibility for deriving weighting factors is the conversion of the verbal predicates into numerical factors (e.g. low = 1; moderate = 2; medium = 3; large = 4; very large = 5), which can again be converted into the percentage total weighting (*cf.* last column of *Table 5*). These preliminary weighting factors should give a rough order of magnitude for the differentiation of the significance of the individual criteria in the experts' discussion. They have to be investigated with great care, but at least they serve for a first evaluation of the gathered information in an multicriteria decision support. It is important to note that especially the weighting factors are subject to an extensive sensitivity analysis, as described in the following.

Table 4: Preliminary aggregation of the ecological and quantitative relevance of the considered criteria for the cross-media assessment in the case study *sinter production*

| **Criteria**<br><br>**Impact Categories** | **Specific contribution** | **Quantitative relevance according to specific contribution** | **Ecological relevance of the impact category** | **Total relevance** |
|---|---|---|---|---|
| Formation of | | | | |
| Photochemical oxidants | 5.5% | low | large | medium |
| Nutrification | 25.4% | moderate | medium | medium |
| Acidification | 47.0% | medium | medium | medium |
| Human toxicity | 100% | very large | large | very large |
| Ecotoxicity, Air | 45.7% | medium | medium | medium |
| Ecotoxicity, Water | --- | low | medium | moderate |
| Hazardous waste | --- | low | moderate | moderate |
| Protection of the marine environment | --- | low | very large | medium |
| | **Data from mass and energy balance** | | | |
| Fossil energy | --- | low | large | medium |
| Electric energy | --- | low | large | medium |
| Sn | --- | low | medium | moderate |
| Tl | --- | low | large | medium |
| PCDD/PCDF | --- | large | large | large |
| Aquatic emissions | --- | low | medium | moderate |

Table 5: Pragmatic ascertaining of preliminary weighting factors in the case study *sinter production*

| Impact category | Total relevance (*cf. Table 4*) | Numerical score | Total weighting |
|---|---|---|---|
| Photochemical oxidant formation | medium | 3 | $3 \cdot \frac{100\%}{41} = 7.3\%$ |
| Nutrification | medium | 3 | $3 \cdot \frac{100\%}{41} = 7.3\%$ |
| Acidification | medium | 3 | $3 \cdot \frac{100\%}{41} = 7.3\%$ |
| Humantoxicity | very large | 5 | $5 \cdot \frac{100\%}{41} = 12.2\%$ |
| Ecotoxicity, Air | medium | 3 | $3 \cdot \frac{100\%}{41} = 7.3\%$ |
| Ecotoxicity, Water | moderate | 2 | $2 \cdot \frac{100\%}{41} = 4.9\%$ |
| Hazardous waste | moderate | 2 | $2 \cdot \frac{100\%}{41} = 4.9\%$ |
| Pollution of the maritime environment | medium | 3 | $3 \cdot \frac{100\%}{41} = 7.3\%$ |
| **Data from mass and energy balance** | | | |
| Fossil energy | medium | 3 | $3 \cdot \frac{100\%}{41} = 7.3\%$ |
| Electricity | medium | 3 | $3 \cdot \frac{100\%}{41} = 7.3\%$ |
| Sn | moderate | 2 | $2 \cdot \frac{100\%}{41} = 4.9\%$ |
| Tl | medium | 3 | $3 \cdot \frac{100\%}{41} = 7.3\%$ |
| PCDD/PCDF | large | 4 | $4 \cdot \frac{100\%}{41} = 9.8\%$ |
| Aquatic emissions | moderate | 2 | $2 \cdot \frac{100\%}{41} = 4.9\%$ |
| | Sum of the scores: | 41 | |

For supporting the evaluation of a multitude of criteria and weightings, a formal method for multicriteria decision support is suggested in the proposed assessment approach. The formal evaluation is based on pairwise comparisons (also called "Outranking"; for a comprehensive explanation of the pairwise comparisons, cf. (SPENGLER et al., 1998; RENTZ et al., 1998; BRANS et al., 1986; Chevalier & Le Téno, 1996). Within the formal evaluation based on pairwise comparisons, the data from the decision table are processed by using an imaginary figure of "preferability with regard to each criterion", called preference. The method uses questions like "Is Technique A better than Technique B with regard to the considered criterion?" The result of the method is a graphical representation of the pairwise comparisons on the basis of the data given in the decision table.

If the preliminary weights as suggested in Table 5 are taken into account, the formal method reveals a graphical representation based on the calculated relative strength and relative weakness of the considered techniques (as the "positive" and "negative" preferences) (→ *Figure 5*).

By means of a sensitivity analysis (→ *Table 6*) it is investigated, for which changes of the weighting such a change in the measure for the relative strength and weakness results, so that a change in the graphical evaluation of the examined techniques follows. In this context, the sensitivity intervals give the range, in which the weighting of the criteria can be altered *ceteris paribus* (under otherwise unchanged conditions), without any rank reversals of the examined techniques. The narrower the interval boundaries, the more sensitive is

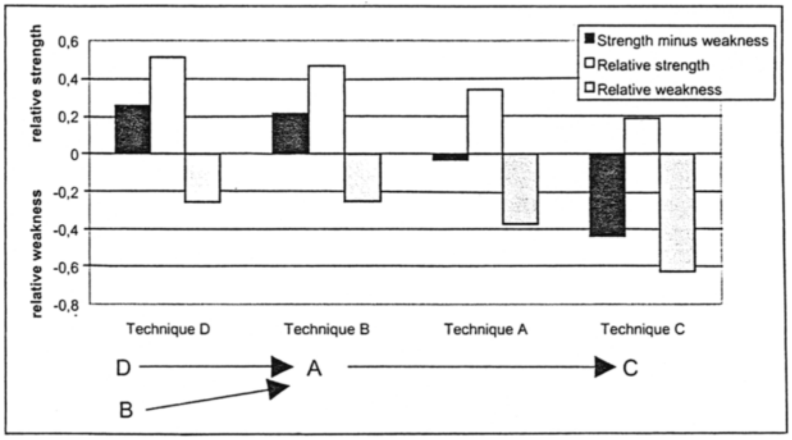


Fig. 5: Graphical representation of the relative strengths and weaknesses as a result of the pairwise comparisons of the considered techniques with regard to the examined criteria and chosen weighting factors

the weighting of the respective criterion. In column 3 of **Table 6**, the sensitivity is roughly classified, so that the experts' discussion can be focused on the criteria with the highest sensitivity. Both of the last columns in **Table 6** show the rankings which result from an alteration of the respective weighting below or above the interval boundaries. With this requisite for sensitivity analysis, it is possible to perform a sound critical review, as it is also requested for by the ISO 14040.

Both **Figure 5** and **Table 6** are to be interpreted by the experts. They might judge that technique B and D come off well, while technique A is in the medium range. Extensive sensitivity analyses show that technique C is always the worst in comparison with the other three techniques (→ *Table 6*).

This result seems to be reasonable: Technique C, using a cyclone, has been refitted with a modern emission reduction technique in the meantime. Technique B, using a fabric filter in addition to an electric precipitator, reaches better results than technique A, the average of three techniques using only an electric precipitator. Technique D, using the airfine process, seems to reach a similar level of protection of the environment as a whole as technique B, since lower emissions into air are partly offset by the aquatic emissions.

For the final decision about the group of BAT, the experts have to keep in mind which masses and energies have been considered for detailed investigation and which have been left out as less relevant. In the case study, the share of the

Table 6: Sensitivity analysis for the chosen weighting for the four examined techniques for sinter production

| Criterion<br>Impact category | Weighting<br>(→ *Table 5*) | Sensitivity interval | | Sensitivity | Alterations at lower interval boundary | Alterations at upper interval boundary |
|---|---|---|---|---|---|---|
| Photochemical oxidant formation | 7.3% | [0%; | 12.1%] | medium | | D → B → A → C |
| Nutrification | 7.3% | [0%; | 10.2%] | medium | B → D → A → C | B → D → A → C |
| Acidification | 7.3% | [0%; | 10.6%] | medium | B → D → A → C | D → B → A → C |
| Humantoxicity | 12.2% | [1.2%; | 43.3%] | low | | D → B → A → C |
| $Ecotoxicity_{Air}$ | 7.3% | [0%; | 11.1%] | medium | | D → B → A → C |
| $Ecotoxicity_{Water}$ | 4.9% | [4.1%; | 16.4%] | high | D → B → A → C | D → B → A → C |
| Hazardous wastes | 4.9% | [4.1%; | 16.4%] | high | D → B → A → C | B → A → C<br>B → D → C |
| Protection of the marine environment | 7.3% | [0%; | 100%] | none | | |
| Fossile energy | 7.3% | [4.2%; | 38.2%] | medium | D → B → A → C | B → D → A → C |
| Electricity | 7.3% | [0%; | 13.2%] | medium | | D → B → A → C |
| Sn | 4.9% | [4.5%; | 22.3%] | high | D → B → A → C | B → D → A → C |
| Tl | 7.3% | [1.9%; | 53.0%] | low | D → B → A → C | B → D → A → C |
| PCDD/PCDF | 9.8% | [0%; | 100%] | none | | |
| Aquatic emissions | 4.9% | [4.7%; | 16.4%] | very high | D → B → A → C | B → A → C<br>D → C |

energy for the impact potentials is about 2% (5% for nutrification) and can therefore be neglected for the final decision on BAT. With this final interpretation by the experts it becomes evident that the proposed cross-media assessment method only supports the decision, which itself is left to the experts.

## 4 Discussion

The IPPC-Directive requires the determination of best available techniques (BAT) in the mentioned industrial sectors following an integrated approach for the protection of the environment as a whole. A suitable method for the assessment of cross-media aspects, however, is not yet available. Since the LCA also aims at an assessment of ecological consequences and is not limited to the consideration of single media, a transposition of the achievements of the LCA discussion towards the determination of BAT seems to be reasonable. The application of the proposed approach for the integrated assessment of sinter techniques as well as further examples from the metal industry (primary aluminium production and electric steel making, *cf.* RENTZ et al., 1998) lead to the following conclusions:

1. In the practical application of the integrated method of assessment for BAT determination, the experts' discussion within the TWGs may be structured by means of flow charts. As soon as the determining of the BAT is considered to be clear in the experts' discussion, the decision is made and the method ends. The extent of the examination is reduced through an early limitation of the examination scope, so that only the necessary data is collected. But especially when first determining the BAT, an iterative procedure appears necessary. This means that some steps of the method should be repeated with more detailed data, if necessary.
2. An important aspect of the approach is its flexibility. It is possible to apply the method step by step and to end the procedure as soon as the experts can determine the BAT. Even with the shortened application, a co-ordinated proceeding in the experts' discussion is ensured which results in a transparent, documented BAT determination for the considered techniques.
3. Due to varying input amounts and different measuring programmes, the data are not directly comparable. Therefore, the currently available technique descriptions have to be supplemented by practice-oriented assumptions and/or through literary research as well as company surveys, but basically, the preparation of the BAT determination can be done with the designed method.
4. The cross-media assessment of the techniques is aligned with the impact potentials of the techniques. With the method following the discussion and further development of the LCA, existing earlier work can be used as a basis. It must be noted, however, that further scientific research for the impact assessment is needed. With regard to other activities in the European environment policy, synergies can also be used, for example in the co-operative use of uniform pollutant registers (e.g. PER Polluting Emissions Register). Hereby, the legal safety is increased for the industrial sectors concerned.
5. Due to the modular structure, the cross-media method of assessment can be adapted to the requirements made of different industrial sectors. The calculation of human toxicity and of ecotoxicity as well as the protection of the marine environment category are currently a first approximation for the potential impacts caused by aquatic emissions, which require closer examination. For the consideration of sector-specific environmental impacts, the definition of further impact categories appears to be possible. Since the emissions are determined both by the inputs and the actual technique, the experts should consider the various impacts explicitly in the assessment procedure, e.g. by meaningful efficiency rates, where appropriate. A supplementation of the integrated assessment method by suitable requirements is possible for the local application through the additional integration of impact categories into the method at a mainly local level. The dynamic continuation of the method is made easier by gradually adapting the first only pragmatically formulated impact categories to the latest scientific achievements.
6. The weighting of impact categories and of mass and energy flows, which are relevant for the decision, shows the subjective assessments of the experts, permitting a structured course of action and directing the discussion to the relevant issues. As far as possible, the weighting should be oriented towards the natural science, which might be achieved by considering the ecological relevance of the impact categories and the quantitative relevance of the impact potentials of the EU, if European emission data are available.
7. According to the IPPC-Directive, the BAT determination is to be done explicitly by "...taking into consideration the costs and advantages..." (Article 2), and, furthermore, the consideration of the economic and technical tenability for the concerned industrial sector is required. According to Annex IV ("...bearing in mind the likely costs and benefits of a measure..."), economic aspects are also to be taken into account when determining BAT. It might be argued, that normally only those techniques can become BAT candidates, which have already been tested on an industrial scale. Otherwise, the consideration of economic and technical criteria is also possible within the formal evaluation, since within this multicriteria method, all units of measurement are converted into a dimensionless measure of preference.
8. The data formats are designed so that the assessment process can be performed efficiently with computer support. This has several advantages:
   - access of the entire TWG to the available information,
   - simple integration of new information into the techniques,
   - simple actualisation/adaptation and modification of the impact factors, and
   - access of interested parties to certain data.

## 5 Conclusions

According to the discussion, the following conclusions can be drawn for the further discussion of an approach for the assessment of cross-media aspects for BAT determination:

1. At first, in a test stage, the cross-media aspects assessment method should be applied in parallel with the currently used decision mechanisms for the identification of BAT. Thus, sector-specific characteristics, the amount of data required, data quality and coordination efforts can be determined.
2. The decision on relevant and not relevant mass and energy flows should be made on the basis of comprehensive ecological assessments of selected techniques in the individual industrial sectors.
3. The impact categories are to be adapted to the state of scientific research at regular intervals, since they are at an early stage of development and still disputable. In this context, the discussion on LCA should be observed. For certain industrial sectors, special impact categories are to be formulated, if necessary, in an experts' discussion in order to adequately take into account the specific ecological features.

Finally, it should be remarked, that, due to the complexity of the implementation of the IPPC Directive, any assessment method can allow only a simplified representation of the current situation by stressing individual problems. A complete interconnection of the single problems will, however, remain an unrealistic aim even in the future. A structured procedure according to consistent rules will, however, allow a more transparent and efficient decision on BAT at EU-level and will thus contribute to the harmonisation of the requirements of industrial installations in the EU.

#### Acknowledgement

The French-German Institute for Environmental Research (Deutsch-Französisches Institut für Umweltforschung, DFIU) at the University of Karlsruhe (TH) is supporting the UBA by carrying out the project "Exemplary investigation into the state of the practical realisation of integrated environmental protection within the metal industry and development of general requirements" (Research Reference Number 109 05 006). This paper considers results of the discussions in the UBA working group "Method for the determination of BAT taking into account cross-media aspects", which was accompanied by the DFIU. Main topics have been presented at an international "Workshop on the assessment of cross-media aspects relevant for the determination of "Best Available Techniques" in the frame of the implementation of Article 16(2) of the IPPC Directive" in February 1998 in Berlin, which has been organised and sponsored by the Federal Environmental Agency (UBA Berlin), the European Commission DG XI and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) (*cf.* GELDERMANN et al., 1998). Particular thanks is expressed to Dr. Karl-Heinz ZIEROCK from the UBA, who as head of the project has contributed greatly to making it a success.

## 6 References

BOTHE, R. (1993): Umweltproblematik bei der Eisenerzsinterung, Dissertation, Aachen

BRANS, J. P.; VINCKE, PH.; MARESCHAL, B. (1986): How to select and how to rank projects: The PROMETHEE method. European Journal of Operational Research 24, S. 228-238

CAPPEL, F.; WENDEBORN, H. (1973): Sintern von Eisenerzen, Stahleisenbücher Bd. 19, Stahleisen, Düsseldorf

CHEVALIER, J.L.; LE TÉNO, J.F. (1996): Life Cycle Analysis with Ill-Defined Data and its Application to Building Products. International Journal of LCA, Vol.1 (2) pp. 90-96

Dutch Ministry of Housing, Spatial Planning and the Environment, Directorate for Air and Energy, Department of Industry: Dutch Notes on BAT for Production of Primary Iron and Steel, Final Report – April 1997

GELDERMANN, J. JAHN, C.; SPENGLER, T.; RENTZ, O. (1998): Proposal for an integrated approach for the assessment of cross-media aspects relevant for the determination of "Best Available Techniques" BAT in the European Union. Proceedings of the "Workshop on the assessment of cross media aspects relevant for the determination of "Best Available Techniques" in the frame of the implementation of Article 16(2) of the IPPC Directive", Berlin

HEIJUNGS, R.; GUINÉE, J.B.; UDO DE HAES, H.A.; WEGENER SLEESWIJK, A.; ANSEMS, A.M.M.; EGGELS, P.G.; VAN DUIN, R.; DE DOEDE, H.P. (1992): Environmental Life Cycle Assessment of Products, Guide & Backgrounds, Centre of Environmental Science, Leiden

MERKEL, A. (1996): Foreword: ISO 14040. International Journal of LCA, 2 p. 121

OWEN; J.W. (1996): LCA Impact Assessment Categories – Technical Feasibility and Accuracy. International Journal of LCA, 1 pp. 151-159

RENTZ, O.; GELDERMANN, J. JAHN, C.; SPENGLER, T. (1998): Proposal for an integrated approach for the assessment of cross-media aspects relevant for the determination of "Best Available Techniques" BAT in the European Union – Project Report on behalf of the UBA (Berlin). Deutsch-Französisches Institut für Umweltforschung (DFIU), Karlsruhe, (also available in German)

SINGHOFEN, A.; HEMMING, C.R.; WEIDEMA, B.P. GRISEL, L.; BRETZ, R., DE SMET, B.; RUSSELL, D. (1996): Life Cycle Inventory Data: Development of a Common Format. International Journal of LCA 1 pp. 171-178

SPENGLER, T.; GELDERMANN, J.; HÄHRE, S.; SIEVERDINGBECK, A.; RENTZ, O. (1998): Development of a Multiple Criteria Based Decision Support System for LCA - Case Study: Tinplate Production. Journal of Cleaner Production, Vol. 6, No. 1, pp. 37-52

TROGE, A. (1997): Begrüßung und Einführung des Seminars "Produktbezogene Ökobilanzen". Proceedings of the UTECH (Umwelttechnologieforum) Berlin

UBA-Berichte 96/05; RENTZ, O.; PÜCHERT, H.; PENKUHN, T., SPENGLER, T. (1996): Stoffstrommanagement in der Eisen- und Stahlindustrie – Konkretisierung des § 5 Abs. 1 Nr. 3 Bundes-Immisionsschutzgesetz. (Forschungsbericht 95-104 06 001) Erich Schmidt Verlag, Berlin

UBA-Texte 52/95; SCHMITZ, S.; OELS, H.-J.; TIEDEMANN, A. (1995): Ökobilanz für Getränkeverpackungen. Berlin (english version: UBA-Texte 19/96: Life-cycle assessment for drinks packaging systems.)

Received: June 19th, 1998
Accepted: September 24th, 1998